Reply To Examiner's Remarks

Claims 1, 4-10, 13-20, 23-30 and 33-38, as amended, are presented for consideration.

The Examiner objects to the drawings under 37 C.F.R. 1.83(a) as not showing, in Figures 1-2, the features disclosed in the specification and recited in claims 19-38. Formal drawings for Figures 1 and 2 are submitted herein. Formal drawings for new Figures 3-4, which show the features recited in claims 19-38 and disclosed at pages 2 and 5-6 in the specification, are also submitted herein. In Figures 3-4, the process $3\omega \rightarrow 2\omega + \omega \rightarrow \omega + \omega + \omega$ shown in Figures 1-2 is replaced by the process $4\omega \rightarrow 2\omega + 2\omega \rightarrow \omega + \omega + \omega$, which is discussed on pages 2 (Summary of the Invention) and 5-6 (Description of Best Modes of the Invention). Page 5, line 12, of the specification is amended herein to indicate that the processes discussed in that paragraph ($4\omega \rightarrow 2\omega + 2\omega \rightarrow \omega + \omega + \omega$) are illustrated in (new) Figures 3-4. Page 2, lines 20 and 23, and page 5, line 12, are amended herein to include a reference to new Figures 3 and 4. No new matter is presented. The Applicant requests that the Examiner accept new Figures 3-4 as responsive to the Examiner's objection to the drawings and amend the specification, at page 2, lines 20 and 23, and at page 5, line 12, referring to the new Figures 3-4.

The Examiner rejects claims 19-28 under 35 U.S.C. 112, second paragraph, as indefinite, noting that claim 19, line 6, should read "4ω" rather than "3ω." Claim 19 is amended herein to correct this error.

The Examiner rejects claims 1-3, 7-12 and 16-18 under 35 U/S.C. 102(b) as anticipated by disclosures in U.S. Patent No. 5,400,173, issued to Komine, citing especially Figures 1, 3 and 8 of the Komine patent.

The Examiner rejects claims 19-22, 26-32 and 36-38 under 103(a) as obvious in view of disclosures in the Komine patent.

The Examiner rejects claims 4-6, 13-15, 23-25 and 33-35 under 35 U.S.C. 103(a) as obvious in view of the combined disclosures in the Komine patent and in U.S. Patent No. 5,953,154, issued to Akagawa et al.

The Komine patent, in Figures 1, 3 and 8 and the accompanying text, discloses use of a first optical parametric oscillator (OPO) 12 and a second OPO 13 to convert a first photon having a wavelength $\lambda 1 = 1$ μm to a second photon having a wavelength $\lambda 2 = 1.5\text{-}1.6$ μm and a third photon having a wavelength $\lambda 3 = 3\text{-}3.5$ μm. The third photon is separated from the second photon at the output of the first OPO 12 and is discarded. The second photon is received by the second OPO 13 and is converted into a fourth photon having a wavelength $\lambda 4 = 2\text{-}3$ μm and a fifth photon having a wavelength $\lambda 5 = 3\text{-}5$ μm.

The first OPO 12, shown in more detail in Figure 3 of the Komine patent, includes a first mirror 14, a first nonlinear crystal 15 and a second mirror 16. The first mirror 14 receives the first (pump) photon and is coated for high transmission at the wavelengths $\lambda 1$ and $\lambda 3$. The second mirror 16 provides intermediate output signals and is coated for high transmission at the wavelengths $\lambda 1$ and $\lambda 3$. The first mirror 14 is partly reflecting for the second photon at the wavelength $\lambda 2$. The second photon, having wavelength $\lambda 2$, is received from the second mirror 16 by, and becomes a pump photon for, the second OPO 13.

The second OPO 13, shown in more detail in Figure 8 of the Komine patent, includes a third mirror 41, a second nonlinear crystal 42 and a fourth mirror 43. The third mirror 41 is highly reflecting for the fourth photon at wavelength $\lambda 4$ and is highly transmitting for the second, third and fifth photons, of wavelengths $\lambda 2$, $\lambda 3$ and $\lambda 5$. The fourth mirror 43 is partly reflecting for the fourth photon at wavelength $\lambda 4$ and is highly transmitting for the third photon of wavelength $\lambda 3$ and for the fifth photon of wavelength $\lambda 5$. Because the fourth mirror 43 is partly reflecting for photons having the wavelength $\lambda 4$ and is highly transmitting for photons having the wavelength $\lambda 5$, the wavelengths $\lambda 4$ and $\lambda 5$ cannot be substantially equal to each other. If the wavelengths $\lambda 4$ and $\lambda 5$ were substantially equal to each other, it would not be possible to provide (1) a third mirror 41 that is highly reflecting for the fourth photon at wavelength $\lambda 4$ and is highly transmitting for the fifth photon at wavelength $\lambda 5$, and (2) a fourth mirror 43 that is partly reflecting for the fourth photon at wavelength $\lambda 4$ and is highly transmitting for the fifth photon of wavelength $\lambda 5$.

The Akagawa et al patent is cited and applied by the Examiner for its disclosure of positioning two AR-coated mirrors or films, 30 and 32, on the ends of a nonlinear crystal, replacing the end mirrors, 10 and 12, shown in Figure 3, as illustrated in Figure 7 of the Akagawa et al patent. This changes the locations of the reflectors but does not change the frequency-dependent reflection characteristics of the mirrors or films and does not change the number of optical cavities involved.

Claim 1, as amended, of the subject patent application recites a method for converting a first light beam having a first frequency into a second light beam having a second frequency. Method claim 1 recites::

providing an optical cavity that is defined by a cavity axis and first and second mirrors spaced apart along the axis, and by first and second nonlinear crystals, spaced apart along the axis between the first and second mirrors, wherein each of the first mirror and the second mirror is substantially fully transmitting at each of frequencies ω and 3ω and is substantially fully reflecting at a frequency 2ω, where ω is a selected frequency;

providing a laser pump beam having pump photons with associated frequency 3ω within the cavity;

allowing at least one pump photon to pass through and interact with a first crystal, positioned within the cavity, and to undergo a conversion to a first-converted photon and a second-converted photon, having substantially the respective frequencies 2ω and ω;

allowing the first-converted photon to pass through and interact with a second crystal, positioned within the cavity, and to undergo a conversion to a third-converted photon and a fourth-converted photon, each having a frequency substantially equal to ω ; and

allowing the second-converted photon to pass through the second crystal,

whereby the pump photon is converted to three photons, each with a frequency substantially equal to ω , each of which exits from the cavity through at least one of the first mirror and the second mirror.

The first (pump) photon has frequency 3ω (wavelength $\lambda 1$) and is converted within the first crystal to a second photon having a frequency 2ω (wavelength $\lambda 2$)

and a third photon having a frequency ω (wavelength $\lambda 3$). The optical cavity is defined by: (1) the first mirror (corresponds to the first mirror of the Komine patent), which is highly transmitting at the frequencies 3ω and ω (wavelengths $\lambda 1$ and $\lambda 3$ of the Komine patent) and is highly reflecting at the frequency 2ω (wavelength $\lambda 2$ of the Komine patent); and (2) the second mirror (corresponds to the fourth mirror 43 of the Komine patent), which is highly transmitting at the frequencies 3ω and ω (wavelengths $\lambda 1$ and $\lambda 3$ of the Komine patent) and is highly reflecting at the frequency 2ω (wavelength $\lambda 2$ of the Komine patent).

Several differences are evident between the method disclosed by the Komine patent (Figures 1, 3 and 8), with or without the mirror location modification introduced by the Akagawa et al patent, and the invention recited in claim 1 of the subject patent application: (1) the Komine patent relies upon provision of two optical cavities, 12 and 13, while claim 1 of the application recites provision of one optical cavity; (2) the wavelengths $\lambda 4$ and $\lambda 5$ of the Komine patent (Figure 8) cannot be substantially equal to each other (if one of these wavelengths is to be optically separated from the other, as recited in column 8, lines 52-68, of the Komine patent), while the corresponding third-converted and fourth-converted photons in claim 1 of the application must be substantially equal to each other so that each of these photons is transmitted by the second mirror; and (3) the Komine patent discloses production of one photon of a frequency corresponding approximately to ω from a photon of frequency 3ω, while claim 1 recites production of three photons, each of frequency substantially equal to ω, from a photon of frequency 3ω. These three photons, each having a frequency substantially equal to ω, are all passed by the first mirror and by the second mirror recited in claim 1. Because of these substantial differences, the Applicant believes that claim 1 is allowable over, and is not anticipated by or made obvious by, the disclosures in the Komine patent or by the combined disclosures in the Komine patent and the Akagawa et al patent..

It would not have been obvious, from the disclosures in the Komine patent or the combined disclosures of the Komine patent and the Akagawa et al patent, to provide a system that produces three photons, each with a frequency substantially

equal to ω (all of which are issued from the optical cavity), from a photon of frequency 3ω, because the Komine patent focuses on production of three photons with substantially different frequencies ($\lambda 3 \approx \omega, \lambda 4 \approx \omega, \lambda 5 \approx \omega$)

Method claim 7 of the subject patent application, dependent upon amended claim 1, connects the length of the (single) optical cavity with the lengths and refractive indices of the first and second crystals and recites the further steps of:

providing the first nonlinear crystal having a length d(1) and having a refractive index $n(2\omega;1)$ for incident light having the frequency 2ω;

providing the second nonlinear crystal having a length d(2) and having a refractive index $n(2\omega;2)$ for incident light having the frequency 2ω; and

providing the optical cavity with a selected length D that satisfies the relation $\{D + d(1)\cdot(n(2\omega;1) - 1) + d(2)\cdot(n(2\omega;2) - 1)\}\cdot(2\omega/c) = N2\cdot\pi$, [referred to herein as a "lengths equation"]

where N2 is a selected positive integer.

The Komine patent relies upon provision of first and second optical cavities that are not coupled with each other so that provision, in the Komine patent, of a single optical cavity satisfying the length equation set forth in claim 7 is not possible. The method set forth in the combination of claims 1 and 7 in the application is not anticipated by, and is not obvious from, the disclosures in the Komine patent. It would not have been obvious, from the disclosures in the Komine patent and the Akagawa et al patent, to provide a single optical cavity satisfying the cavity length and crystal lengths equation set forth in claim 7, because the Komine patent discloses use of first and second optical cavities with no equation connecting the cavity length and the lengths of the first and second crystals.

Independent system claim 10, as amended, and system claim 16, dependent upon claim 10, correspond to independent method claim 1, as amended, and dependent method claim 7, respectively, and are believed to be allowable for the same reasons that claims 1 and 7 are allowable.

Independent method claim 19, as amended, works with photons having frequencies ω, 2ω and 4ω, rather than with photons with frequencies ω, 2ω and

3ω, as in method claim 1. Method claim 19, as amended, recites a method for converting a first light beam having a first frequency into a second light beam having a second frequency:

providing an optical cavity that is defined by a cavity axis and first and second mirrors spaced apart along the axis , and by first and second nonlinear crystals, spaced apart along the axis between the first and second mirrors, wherein each of the first mirror and the second mirror is substantially fully transmitting at each of frequencies ω and 4ω and is substantially fully reflecting at a frequency 2ω, where ω is a selected frequency;

providing a laser pump beam having pump photons with associated frequency 4ω within the cavity;

allowing at least one pump photon to pass through and interact with a first crystal and to undergo a conversion to a first-converted photon and a second-converted photon, each having a frequency substantially equal to 2ω; ~~and~~

allowing at least one of the ~~first~~ first-converted photon and the second-converted photon to pass through and interact with a second crystal and to undergo a conversion to a third-converted photon and a fourth-converted photon, each of the third-converted and fourth-converted photon having a frequency substantially equal to ω, and

whereby the pump photon is converted to at least two photons, each with a frequency substantially equal to ω, and each of which exits from the cavity through at least one of the first mirror and the second mirror.

Method claim 19, as amended, is analogous to method claim 1, as amended, and is believed to be allowable over the individual or combined disclosures of the Komine patent and the Akagawa et al patent, for reasons that are analogous to the reasons presented in the preceding discussion of claim 1. Method claim 26, dependent upon claim 19, is believed to be allowable for reasons analogous to the reasons set forth in the preceding discussion of claim 7.

Independent system claim 29, as amended, and dependent system claim 36 to method claims 19 and 26, respectively, and are believed to be allowable for the same reasons that claims 19 and 26 are allowable.

Claims 4-9 depend upon claim 1, as amended, and are believed to be allowable if claim 1 is allowable. Claims 13-18 depend upon claim 10, as amended, and are believed to be allowable if claim 10 is allowable. Claims 20 and 23-28 depend upon claim 19, as amended, and are believed to be allowable if claim 19 is allowable. Claims 30 and 33-38 depend upon claim 29, as amended, and are believed to be allowable if claim 29 is allowable

For the foregoing reasons, the Applicant believes that claims 1, 4-10, 13-20, 23-30 and 33-38, as amended, are allowable over the background art cited and applied by the Examiner. The Applicant requests that the Examiner pass the application, as amended and including claims 1, 4-10, 13-20, 23-30 and 33-38, as amended, to issue as a U.S. patent.

Respectfully Submitted,

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